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DESCRIPTION

BRANCHING FILTER AND COMMUNICATION DEVICE

5   Technical Field

The present invention relates to a branching filter

including filters having piezoelectric thin film resonators,

the branching filter being used in a communication device

etc.

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Background Art

In recent years, piezoelectric thin film filters using

elastic bulk waves have been developed.

The above piezoelectric thin film filters are compact

15   in size, have light weight, and are excellent in vibration

resistance and impact resistance. In addition, the

piezoelectric thin film filters have small variation in

products and high reliability, and can provide non-adjusting

circuits. Therefore, the mounting can be automated and

20   simplified. Furthermore, even when the frequency is

increased, the piezoelectric thin film filters can be easily

produced. Thus, the piezoelectric thin film filters have

superior characteristics.

A branching filter (duplexer) including such

25   piezoelectric thin film filters is proposed.

For example, Japanese Unexamined Patent Application Publication No. 2001-24476 discloses a branching filter including piezoelectric thin film filters in which piezoelectric thin film resonators are arranged in a ladder

5   type.

The piezoelectric thin film resonators used in the branching filter disclosed in Japanese Unexamined Patent Application Publication No. 2001-24476 form a transmitting filter and a receiving filter. In both filters, electrodes

10   are composed of Mo and piezoelectric thin films are composed of AlN.

However, the required characteristics are different between the transmitting filter and the receiving filter in the branching filter.

15   In other words, piezoelectric thin film resonators having the same structure are optimized only in either the transmitting filter or the receiving filter.

According to the above Japanese Unexamined Patent Application Publication No. 2001-24476, both of the

20   transmitting filter and the receiving filter have the same structure. Therefore, a branching filter having optimum characteristics in both of the transmitting and the receiving cannot be achieved.

In view of the above problems, it is an object of the

25   present invention to provide a branching filter having

excellent characteristics in which the configuration of the transmitting filter and the receiving filter is optimized.

Disclosure of Invention

5   In order to solve the above problems, a branching filter of the present invention includes a transmitting filter and a receiving filter wherein piezoelectric thin film resonators including at least one piezoelectric thin film sandwiched between at least one pair of facing

10   electrodes are disposed in a ladder type on an opening or a recess of a substrate, the transmitting filter and the receiving filter being connected to an antenna terminal in parallel. In the branching filter, the piezoelectric thin film resonators forming the transmitting filter and the

15   piezoelectric thin film resonators forming the receiving filter have a different structure.

In the branching filter of the present invention, the piezoelectric thin film resonators forming the transmitting filter and the piezoelectric thin film resonators forming

20   the receiving filter preferably include a different piezoelectric film.

In the branching filter of the present invention, the piezoelectric film of the piezoelectric thin film resonators forming the transmitting filter is preferably composed of

25   AlN and the piezoelectric film of the piezoelectric thin

film resonators forming the receiving filter is preferably composed of ZnO.

In the branching filter of the present invention, the material of the electrodes is preferably different between the piezoelectric thin film resonators forming the transmitting filter and the piezoelectric thin film resonators forming the receiving filter.

In the branching filter of the present invention, the acoustic impedance of the material of the electrodes is preferably different between the piezoelectric thin film resonators forming the transmitting filter and the piezoelectric thin film resonators forming the receiving filter.

In the branching filter of the present invention, the frequency of the pass band of the receiving filter is preferably higher than the frequency of the pass band of the transmitting filter, and the acoustic impedance of the material of the electrodes forming the receiving filter is preferably higher than the acoustic impedance of the material of the electrodes forming the transmitting filter.

In the branching filter of the present invention, the piezoelectric thin film resonators forming the transmitting filter preferably use second harmonic waves and the piezoelectric thin film resonators forming the receiving filter preferably use fundamental waves.

In the branching filter of the present invention, in addition to the above configuration, the piezoelectric thin film resonators forming the transmitting filter and the piezoelectric thin film resonators forming the receiving filter preferably include a different insulating film on the opening or the recess of the substrate.

In the branching filter of the present invention, the insulating film of the piezoelectric thin film resonators forming the receiving filter is preferably composed of SiO_2.

In the branching filter of the present invention, the insulating film of the piezoelectric thin film resonators forming the receiving filter is preferably composed of two layers including an SiO_2 layer adjacent to the piezoelectric thin film and an Al_2O_3 layer adjacent to the SiO_2 layer.

In the branching filter of the present invention, the insulating film of the piezoelectric thin film resonators forming the receiving filter is preferably composed of two layers including an SiO_2 layer adjacent to the piezoelectric thin film and an AlN layer adjacent to the SiO_2 layer.

In the branching filter of the present invention, the insulating film of the piezoelectric thin film resonators forming the transmitting filter is preferably composed of two layers including an AlN layer adjacent to the piezoelectric thin film and an SiO_2 layer adjacent to the AlN layer.

In the branching filter of the present invention, the insulating film of the piezoelectric thin film resonators forming the transmitting filter is preferably composed of two layers including an Al_2O_3 layer adjacent to the piezoelectric thin film and an SiO_2 layer adjacent to the Al_2O_3 layer.

A communication device of the present invention includes the above branching filter.

The branching filter of the present invention includes a transmitting filter and a receiving filter wherein piezoelectric thin film resonators including at least one piezoelectric thin film sandwiched between at least one pair of facing electrodes are disposed in a ladder type on an opening or a recess of a substrate, the transmitting filter and the receiving filter being connected to an antenna terminal in parallel. In the branching filter, the piezoelectric thin film resonators forming the transmitting filter and the piezoelectric thin film resonators forming the receiving filter have a different structure.

According to the above configuration, the transmitting filter and the receiving filter include piezoelectric thin film resonators having different structures from each other. As a result, a branching filter having optimum characteristics in both of the transmitting filter and the receiving filter can be advantageously provided.

Brief Description of the Drawings

Fig. 1 is a circuit diagram of a duplexer according to an embodiment of the present invention.

5 Fig. 2 is a schematic cross-sectional view showing the structure of a resonator of a transmitting filter in the duplexer.

Fig. 3 is a schematic cross-sectional view showing the structure of a resonator of a receiving filter in the

10 duplexer.

Fig. 4 is a schematic cross-sectional view showing the structure of a resonator of a receiving filter according to an embodiment of the present invention.

Fig. 5 is a graph showing the displacement of vibration

15 of each layer in an example of the resonator in Fig. 4.

Fig. 6 is a graph showing the relationship between the electromechanical coupling coefficient k^2_{eff} and the film thickness ratio in the resonator in Fig. 4.

Fig. 7 is a graph showing the relationship between Q

20 factor and the film thickness ratio in the resonator in Fig. 4.

Fig. 8 is a graph showing the relationship between the temperature coefficient of frequency (TCF) and the film thickness ratio in the resonator in Fig. 4.

25 Fig. 9 is a schematic cross-sectional view showing the

structure of the resonator in a transmitting filter according to an embodiment of the present invention.

Fig. 10 is a graph showing the displacement of vibration of each layer in an example of the resonator in

5 Fig. 9.

Fig. 11 is a graph showing the relationship between k^2_{eff} and the film thickness ratio in the resonator in Fig. 9.

Fig. 12 is a graph showing the relationship between Q factor and the film thickness ratio in the resonator in Fig.

10 9.

Fig. 13 is a graph showing the relationship between TCF and the film thickness ratio in the resonator in Fig. 9.

Fig. 14 is a circuit diagram showing a modification of the duplexer.

15 Fig. 15 is a circuit diagram showing a modification of the duplexer.

Fig. 16 is a circuit diagram showing a modification of the duplexer.

Fig. 17 is a schematic cross-sectional view showing a

20 modification of the resonator in the transmitting filter and the receiving filter.

Fig. 18 is a graph showing the frequency characteristics of insertion loss in a transmitting filter and a receiving filter according to an embodiment of the

25 present invention.

Fig. 19 is a graph showing the frequency characteristics of insertion loss in a transmitting filter and a receiving filter according to an embodiment of the present invention.

5   Fig. 20 is a graph showing the frequency characteristics of insertion loss in a transmitting filter and a receiving filter in a comparative example.

Fig. 21 is a graph showing the frequency characteristics of insertion loss in a transmitting filter

10   and a receiving filter in a comparative example.

Fig. 22 is a cross-sectional view of a piezoelectric thin film resonator used in a fourth embodiment.

Fig. 23 is a graph showing an investigation result of the electromechanical coupling coefficient with the

15   piezoelectric film thickness ratio in the fourth embodiment.

Fig. 24 is a circuit block diagram of a communication device including a duplexer of the present invention.

Fig. 25 is a schematic cross-sectional view showing the structure of a resonator of a receiving filter according to

20   an embodiment of the present invention.

Best Mode for Carrying Out the Invention

[First Embodiment]

An embodiment of the present invention will now be

25   described with reference to Figs. 1 to 4.

In the present embodiment, a duplexer in which the transmission band is 1,850 to 1,910 MHz and the reception band is 1,930 to 1,990 MHz will now be described.

As shown in Fig. 1, the duplexer (branching filter)
5   according to the present embodiment includes a transmitting terminal 1, a receiving terminal 2, and an antenna terminal 3.

The duplexer includes a transmitting filter 5, a receiving filter 6, and a matching circuit 7.   The
10   transmitting filter 5 is disposed between the antenna terminal 3 and the transmitting terminal 1.   The receiving filter 6 is disposed between the antenna terminal 3 and the receiving terminal 2.   The matching circuit 7 is disposed between the antenna terminal 3 and the receiving filter 6.
15   In other words, in the duplexer, the transmitting filter 5 and the receiving filter 6 are connected to the antenna terminal 3 in parallel.

A capacitance 8 is disposed between the antenna terminal 3 and the transmitting filter 5.
20   The pass band in the transmitting filter 5 and that in the receiving filter 6 are set so as to be different from each other.

The transmitting filter 5 includes series resonators 11a and 11b and parallel resonators 12a and 12b in a ladder
25   type.

The parallel resonators 12a and 12b are grounded through inductances 13a and 13b.

The inductances 13a and 13b can extend the pass band of the transmitting filter 5.

The receiving filter 6 includes series resonators 21a, 21b, and 21c and parallel resonators 22a, 22b, 22c, and 22d in a ladder type.

The parallel resonators 22a, 22b, 22c, and 22d are grounded.

The matching circuit 7 includes an inductance 71 connected in series and capacitances 72 and 73 connected in parallel.

In the present embodiment, the resonators in the transmitting filter 5 and the receiving filter 6 are piezoelectric thin film resonators. Each of the piezoelectric thin film resonators includes a thin film (piezoelectric thin film) composed of a piezoelectric material and electrodes that sandwich the piezoelectric thin film and face each other.

The characteristics desired for the transmitting filter 5 and the receiving filter 6 wherein the transmitting filter has relatively low frequency characteristics and the receiving filter has relatively high frequency characteristics will now be described.

A large electric power is applied to the transmitting

filter 5.

Therefore, the resonators used in the transmitting
filter 5 preferably have a high Q factor.

This Q factor represents the mechanical vibration loss
5   in a resonator.

Since a low Q factor increases the mechanical vibration
loss in the resonator, the loss causes heat and the
resonator generates heat. As a result, the lifetime of the
resonator is shortened.

10   Furthermore, the lifetime of the transmitting filter 5
is also shortened.

The Q factor depends on the structure of the resonator.
Furthermore, the smaller the elastic loss of the material
used in the resonator, the higher the Q factor is.

15   Since the elastic loss of materials also depends on the
frequency etc., it is difficult to mention the specific
values. However, propagation loss, which is often used in,
for example, a surface acoustic wave device, is an indicator.

That is, the smaller the propagation loss of the
20   material used in the resonator, the higher the Q factor of
the resonator is.

A material having a high thermal conductivity is
preferably used as the resonators in the transmitting filter
5.

25   The reason for this is as follows: A low thermal

conductivity decreases the heat dissipation effect. As a result, the resonator is heated and the lifetime of the resonator is shortened.

The electromechanical coupling coefficient k^2 (effective coupling coefficient k^2_{eff}) of the resonators in the transmitting filter 5 is preferably about 3% to about 4%.

The reason for this is as follows: Even when the electromechanical coupling coefficient k^2_{eff} is small, the pass band can be extended to the low frequency side to some degree with an external circuit (for example, an extended inductance).

When the electromechanical coupling coefficient k^2_{eff} is 5% or more, roll-off characteristics at the high frequency side (i.e., the steepness of the attenuation in the range from the pass band of 1,910 MHz in the transmitting to the pass band of 1,930 MHz in the receiving) is deteriorated.

The use of a material having a large electromechanical coupling coefficient k^2 as the piezoelectric thin film increases the k^2_{eff} of the resonator.

The electromechanical coupling coefficient k^2_{eff} also depends on the structure of the resonator.

In the receiving filter 6, when the pass band is extended to the low frequency side with an external circuit, the receiving filter 6 interferes with the transmitting filter 5.

In addition, an external circuit cannot extend the pass band to the high frequency side.

For these reasons, in the receiving filter 6, a predetermined filter band must be provided using resonators
5   having a large electromechanical coupling coefficient k^2_{eff} and without an auxiliary external circuit.

The structure of the piezoelectric thin film resonator of the transmitting filter 5 and the piezoelectric thin film resonator of the receiving filter 6 having the above
10 characteristics will now be described in detail with reference to Figs. 2 and 3.

As shown in Fig. 2, a resonator of the transmitting filter 5 includes a supporting substrate (substrate) 32 composed of silicon (Si) and an insulating film 31 disposed
15 on the supporting substrate 32.

Furthermore, the supporting substrate 32 includes an opening (hollow part) that penetrates the supporting substrate 32 in the direction of the thickness and extends to the other side of the insulating film 31.
20 A lower electrode (electrode) 33, a piezoelectric thin film 34, and an upper electrode (electrode) 35 are disposed on the insulating film 31 in that order.

The insulating film 31 forms a diaphragm.

This diaphragm faces the opening (hollow part).
25 As shown in Fig. 3, a resonator of the receiving filter

6 includes a supporting substrate (substrate) 42 composed of
silicon (Si) and an insulating film 41 disposed on the
supporting substrate 42.

Furthermore, the supporting substrate 42 includes an
5   opening (hollow part) that penetrates the supporting
substrate 42 in the direction of the thickness and extends
to the insulating film 41.

A lower electrode 43, a piezoelectric thin film 44, and
an upper electrode 45 are disposed on the insulating film 41
10 in that order.

The insulating film 41 forms a diaphragm.

This diaphragm faces the opening (hollow part).

Second harmonic waves are used in the resonators shown
in Figs. 2 and 3.

15 In the present embodiment, the kind of the
piezoelectric thin film is different between the resonators
of the transmitting filter 5 and the resonators of the
receiving filter 6.

In the resonators of the transmitting filter 5, the
20 piezoelectric thin film 34 is composed of AlN, the
insulating film 31 is composed of SiO_2, and the lower
electrode 33 and the upper electrode 35 are composed of
Au/Ti.

In the resonators of the receiving filter 6, the
25 piezoelectric thin film 45 is composed of ZnO, the

insulating film 41 is composed of SiO_2, and the lower
electrode 43 and the upper electrode 45 are composed of
Au/Ti.

The resonators of the transmitting filter 5 will now be
described in more detail.

Aluminum nitride (AlN) has a thermal conductivity
higher than that of ZnO and has an elastic loss smaller than
that of ZnO.

Aluminum nitride (AlN) has a small electromechanical
coupling coefficient (k_t=0.23, thermal conductivity
$W/(m \cdot °C)$=150).

Accordingly, the resonators of the transmitting filter
5 have a Q factor and a heat dissipation effect higher than
those of the resonators of the receiving filter 6.

Furthermore, in the resonators of the transmitting
filter 5, the insulating film 31 composed of SiO_2 is used.
Therefore, the sign of the temperature coefficient of the
insulating film 31 composed of SiO_2 and that of the
piezoelectric thin film 34 composed of AlN are opposite with
respect to each other.

Therefore, the temperature change is cancelled out in
the piezoelectric thin film 34 and the insulating film 31.
As a result, the temperature characteristics in the
resonators of the transmitting filter 5 can be improved.

The acoustic velocity in AlN is larger than that in ZnO.

In order to obtain the equivalent frequency as that of the
resonator using ZnO, the film thickness of the diaphragm
must be increased or an electrode material having a large
density must be used.

5   When the film thickness of AlN is increased, the area
(vibration part) where the upper electrode 35 is overlapped
with the lower electrode 33 must be increased in order that
the capacitance (C_0) of the resonator is controlled to be a
predetermined value. As a result, the element size is

10   increased.

However, a metal having a density of at least 8 g/cm^3
(for example, Au: 19.3, Pt: 21.45, Ni: 8.9, and Mo: 10.4)
can be used as at least one of the upper electrode 35 and
the lower electrode 33. In this case, the predetermined

15   frequency can be obtained without increasing the area of the
upper electrode 35 or the lower electrode 33.

The resonators of the receiving filter 6 will now be
described in more detail.

Zinc oxide (ZnO) has an electromechanical coupling

20   coefficient larger than that of AlN ($k_t=0.30$).

Accordingly, the resonators of the receiving filter 6
have a large electromechanical coupling coefficient k^2_{eff}.

Zinc oxide (ZnO) has a thermal conductivity lower than
that of AlN (thermal conductivity W/(m·°C)=4).

25   Furthermore, in the resonators of the receiving filter

6, the insulating film 41 composed of SiO_2 is used.

Therefore, the sigh of the temperature coefficient of the insulating film 41 composed of SiO_2 and that of the piezoelectric thin film 44 composed of ZnO are opposite with respect to each other.

Therefore, the temperature change is cancelled out in the piezoelectric thin film 44 and the insulating film 41. As a result, the temperature characteristics in the resonators of the receiving filter 6 can be improved.

In the resonators of the transmitting filter 5, AlN having a small electromechanical coupling coefficient k^2_{eff} is used as the piezoelectric thin film 34. Therefore, the electromechanical coupling coefficient k^2_{eff} of the resonators of the transmitting filter is smaller than that of the resonators of the receiving filter.

As shown in Fig. 1, the inductances 13a and 13b are connected to the parallel resonators 12a and 12b of the transmitting filter 5. Therefore, in this case, the pass band can be extended to the low frequency side, thereby obtaining the desired bandwidth.

[Second Embodiment]

An embodiment of the present invention will now be described with reference to Figs. 4 to 8.

For the convenience of description, components having the same function as those of the components shown in the

first embodiment have the same reference numerals and the description is omitted.

In the present embodiment, as shown in Fig. 4, an insulating film 41 in the resonators of the receiving filter 6 is composed of two layers: An insulating film 41a is disposed on a substrate 42 and an insulating film 41b is disposed on the insulating film 41a.

In the present embodiment, the insulating film 41a is preferably composed of Al_2O_3 and the insulating film 41b is preferably composed of SiO_2.

In this structure, a compressive stress is applied on the piezoelectric thin film 44 composed of ZnO and the insulating film 41b composed of SiO_2, whereas a tensile stress is applied on the insulating film 41a composed of Al_2O_3.

This structure can stabilize the strength of the diaphragm.

In the present embodiment, the insulating film 41a may be composed of AlN.

In this case, the sigh of the temperature coefficient of the insulating film 41a composed of AlN and that of the insulating film 41b composed of SiO_2 are opposite with respect to each other.

Therefore, the temperature change is cancelled out in the insulating film 41a and the insulating film 41b. As a

result, the temperature characteristics in the resonators of the receiving filter 6 can be improved.

Furthermore, since AlN is superior in the thermal conductivity compared with Al_2O_3, the heat dissipation effect

5 can be improved.

The above structure can increase the electromechanical coupling coefficient k^2_{eff}.

This is because the acoustic impedance of SiO_2 forming the insulating film 41b is 1.3×10^7 ($N \cdot s/m^3$), which is smaller

10 than that of ZnO (3.5×10^7 ($N \cdot s/m^3$)) forming the piezoelectric thin film 44, that of Al_2O_3 (3.9×10^7 ($N \cdot s/m^3$)) and that of AlN (3.5×10^7 ($N \cdot s/m^3$)) forming the insulating film 41a.

In other words, acoustic waves are significantly reflected at the interface between the piezoelectric thin

15 film 44 and the insulating film 41b, and the energy of the acoustic waves is concentrated on the piezoelectric thin film 44. Accordingly, the electromechanical coupling coefficient k^2_{eff} can be increased.

As shown in the displacement diagram of vibration in

20 Fig. 5, the displacement of vibration in ZnO of the piezoelectric thin film 44 is larger than that in SiO_2 of the insulating film 41b.

The thickness of the piezoelectric thin film 44, the insulating film 41a composed of Al_2O_3, and the insulating

25 film 41b composed of SiO_2 will now be described. As shown

in Fig. 6, in terms of large electromechanical coupling coefficient k^2_{eff}, the film thickness ratio represented by the thickness of the piezoelectric thin film 44 : (the thickness of the insulating film 41a composed of Al_2O_3 + the thickness of the insulating film 41b composed of SiO_2) is preferably 0.7 to 1.3.

Furthermore, as shown in Fig. 7, in terms of high Q factor, the film thickness ratio is preferably 0.6 to 0.8.

As shown in Fig. 8, in terms of small absolute value of the temperature coefficient of frequency (TCF), the film thickness ratio represented by the insulating film 41a (Al_2O_3) : the insulating film 41b (SiO_2) is preferably 1 or more.

However, when the ratio of the insulating film 41a to the insulating film 41b is excessively small, the problem of stress balance occurs. Therefore, the film thickness ratio represented by the insulating film 41a (Al_2O_3) : the insulating film 41b (SiO_2) is more preferably 1 to 3.

In Figs. 6 to 8, the piezoelectric thin film 44 is composed of ZnO, the insulating film 41a is composed of Al_2O_3, and the insulating film 41b is composed of SiO_2.

The upper electrode 45 and the lower electrode 43 that sandwich the piezoelectric thin film 44 are composed of Al and have a film thickness of 180 nm.

The figures show the calculation results in which the

film thickness ratio of the insulating film 41b (SiO_2) to the insulating film 41a (Al_2O_3) is varied from 3:1 to 1:3 under the above conditions.

The absolute amount of each film thickness is determined such that the frequency band of the resonators is controlled to be 1,900 MHz.

[Third Embodiment]

An embodiment of the present invention will now be described with reference to Figs. 9 to 17.

For the convenience of description, components having the same function as those of the components shown in the first embodiment and the second embodiment have the same reference numerals and the description is omitted.

In the present embodiment, as shown in Fig. 9, an insulating film 31 in the resonators of the transmitting filter 5 is composed of two layers: An insulating film 31a is disposed on a substrate 32 and an insulating film 31b is disposed on the insulating film 31a.

In the present embodiment, the insulating film 31a is preferably composed of SiO_2 and the insulating film 31b is preferably composed of AlN.

In this case, since AlN is superior in the thermal conductivity, the heat dissipation effect of the element can be improved.

This structure can achieve high withstand power, extend

the lifetime, and improve the reliability of the element.

In the present embodiment, the insulating film 31a may be composed of SiO_2 and the insulating film 31b may be composed of Al_2O_3.

5   In this structure, a compressive stress is applied on the insulating film 31a composed of SiO_2, whereas a tensile stress is applied on the insulating film 31b composed of Al_2O_3.

This structure can stabilize the strength of the
10 diaphragm.

The above structure can decrease the absolute value of the temperature coefficient of frequency (TCF).

The reason for this is as follows: The temperature coefficient of ZnO, Al_2O_3, and AlN that are used as the
15 piezoelectric thin film 34 or the insulating film 31b is negative (i.e., the rise in temperature decreases the frequency). On the other hand, the temperature coefficient of SiO_2 used as the insulating film 31a is positive.

As shown in the displacement diagram of vibration in
20 Fig. 10 (wherein ZnO is used as the piezoelectric thin film 34), the displacement of vibration in ZnO of the piezoelectric thin film 34 is strongly affected by the temperature coefficient of SiO_2 forming the insulating film 31a. As a result, the TCF of the whole resonator is shifted
25 in the positive direction (i.e., comes close to zero).

When the above piezoelectric thin film 34, the insulating film 31a composed of SiO_2, and the insulating film 31b composed of Al_2O_3 are used, the thickness of the insulating film 31a and the insulating film 31b is

5   preferably as follows. As shown in Figs. 11 and 12, in terms of large electromechanical coupling coefficient k^2_{eff} and high Q factor, since the dependency to the thickness of the piezoelectric thin film 34 is small, the film thickness ratio is not particularly limited. However, the film

10 thickness ratio represented by the thickness of the piezoelectric thin film 34 : (the thickness of the insulating film 31a composed of SiO_2 + the thickness of the insulating film 31b composed of Al_2O_3) is preferably 0.7 to 1.2.

15   As shown in Fig. 13, in terms of small absolute value of the temperature coefficient of frequency (TCF), the film thickness ratio represented by the insulating film 31a (SiO_2) : the insulating film 31b (Al_2O_3) is preferably 1 or more.

20   However, when the ratio of the insulating film 31a (SiO_2) to the insulating film 31b (Al_2O_3) is excessively small, the problem of stress balance occurs. Therefore, the film thickness ratio represented by the insulating film 31a (SiO_2) : the insulating film 31b (Al_2O_3) is more preferably 1

25 to 3.

In Figs. 11 to 13, the piezoelectric thin film 34 is composed of ZnO, the insulating film 31a is composed of SiO_2, and the insulating film 31b is composed of Al_2O_3.

The upper electrode 35 and the lower electrode 33 that sandwich the piezoelectric thin film 34 are composed of Al and have a film thickness of 180 nm.

The figures show the calculation results in which the film thickness ratio of the insulating film 31b (Al_2O_3) to the insulating film 31a (SiO_2) is varied from 3:1 to 1:3 under the above conditions.

The absolute amount of each film thickness is determined such that the frequency band of the resonators is controlled to be 1,900 MHz.

As shown in Fig. 14, the receiving filter may include two series resonators and three parallel resonators.

As shown in Fig. 15, in the transmitting filter, a resonator may be added in series adjacent to the transmitting terminal. The matching circuit may include two inductances connected in series and a capacitance connected in parallel. Furthermore, the capacitance 8 may be omitted.

As shown in Fig. 16, each of the series resonators in the transmitting filter in Fig. 14 may be replaced with two series resonators.

A modification of the resonator in the transmitting filter 5 and the receiving filter 6 will now be described

with reference to Fig. 17.

As shown in Fig. 17, the resonator includes an insulating film 51 on a recess 56 disposed on a substrate 52. The insulating film 51 is suspended over the recess 56 at

5   the periphery.

A lower electrode 53, a piezoelectric thin film 54, and an upper electrode 55 are disposed on the insulating film 51.

The above structures of the piezoelectric thin film and the insulating film in the transmitting filter 5 and the

10   receiving filter 6 can be applied to this structure. Thus, the same advantages can be achieved in this structure.

In addition, when the resonators of the transmitting filter 5 and the resonators of receiving filter 6 are composed of the same materials and are different only in the

15   deposited order, the same deposition equipment can be used to reduce the cost.

The transmitting filter 5 using resonators including a piezoelectric thin film 34 composed of ZnO, an insulating film 31a composed of SiO_2, and an insulating film 31b

20   composed of AlN can achieve a Q factor of 700 and an electromechanical coupling coefficient k^2_{eff} of 2.9%.

The receiving filter 6 using resonators including a piezoelectric thin film 44 composed of ZnO, an insulating film 41a composed of Al_2O_3, and an insulating film 41b

25   composed of SiO_2 can achieve a Q factor of 400 and an

electromechanical coupling coefficient k^2_{eff} of 5.3%.

Figs. 18 and 19 show the frequency characteristics of insertion loss in the transmitting filter 5 and the receiving filter 6.

5   In the transmitting filter 5, the inductances are connected to the parallel resonators. Therefore, as shown in Figs. 18 and 19, the bandwidth can be extended to the low frequency side despite the small electromechanical coupling coefficient k^2_{eff}.

10   In contrast, in the receiving filter 6, the bandwidth can be increased because of the large electromechanical coupling coefficient k^2_{eff}.

As shown in Fig. 19, regarding the bandwidth wherein the level is attenuated by 3.5 dB, the transmitting filter 5

15   can provide the bandwidth of 80 MHz, and the receiving filter 6 can provide the bandwidth of 68 MHz.

As a comparative example, a receiving filter 6 using resonators including a piezoelectric thin film 44 composed of ZnO, an insulating film 41a composed of SiO_2, and an

20   insulating film 41b composed of AlN is used. The resonators have a Q factor of 700 and an electromechanical coupling coefficient k^2_{eff} of 2.9%. As shown in Figs. 20 and 21, in this receiving filter 6, the bandwidth wherein the level is attenuated by 3.5 dB is no more than 36 MHz.

25   [Fourth Embodiment]

In the present embodiment, the resonance characteristics in a piezoelectric thin film resonator 100 shown in Fig. 22 were investigated.

The piezoelectric thin film resonator 100 includes a
5 supporting substrate (substrate) 102 composed of silicon (Si).

A lower electrode (electrode) 103, a piezoelectric thin film 104 composed of ZnO, and an upper electrode (electrode) 105 are disposed on the supporting substrate 102 in that
10 order.

Furthermore, the supporting substrate 102 includes an opening (hollow part) that penetrates the supporting substrate 102 in the direction of the thickness and extends to the other side of the lower electrode 103.

15 A diaphragm facing the opening (hollow part) is formed.

In this experiment, the upper electrode 105 and the lower electrode 103 in the piezoelectric thin film resonator 100 were composed of the same material and had the same film thickness.

20 The material of the electrodes used in this example was aluminum Al, molybdenum Mo, copper Cu, tungsten W, and platinum Pt.

Fig. 23 shows the investigation result of the relationship between a piezoelectric film thickness ratio
25 and the electromechanical coupling coefficient (k^2_{eff})

concerning the various materials of the electrodes. The

piezoelectric film thickness ratio is the ratio of the film

thickness of the piezoelectric thin film to the total film

thickness (the thickness of the upper electrode 105 + the

5   thickness of the piezoelectric thin film 104 + the thickness

of the lower electrode 103) of the resonator.

As shown in Fig. 23, when the piezoelectric film

thickness ratio was optimally selected, among the above five

kinds of materials of the electrodes, the highest

10   electromechanical coupling coefficient (k^2_{eff}) was achieved

with W, and subsequently, Pt, Mo, Cu, and Al, in that order.

Table 1 shows the approximate acoustic impedance and

the resistivity in the materials of the electrodes.

15   [Table 1]

Material of electrodes	Acoustic impedance (Ns/m^3)	Resistivity ($\mu\Omega cm$)
W	1.0×10^8	5.5
Pt	7.5×10^7	10.6
Mo	6.9×10^7	5.7
Cu	3.9×10^7	1.7
Al	1.7×10^7	2.7

Referring to Fig. 23 and Table 1, the higher the

acoustic impedance of the material, the higher the electromechanical coupling coefficient (k^2_{eff}) can be.

As shown in the first embodiment to the third embodiment, resonators having a large electromechanical

5   coupling coefficient (k^2_{eff}) must be used in a filter (for example, receiving filter) disposed at the high frequency side of the duplexer.

In a filter (for example, transmitting filter) disposed at the low frequency side, the band can be extended by

10 providing an external inductance. Therefore, even when resonators having a small electromechanical coupling coefficient (k^2_{eff}) are used, the steepness of the filter can be provided.

Accordingly, in the receiving filter, a material that

15 has high acoustic impedance to increase the electromechanical coupling coefficient (k^2_{eff}) is preferably used as the electrodes.

On the other hand, in the transmitting filter, copper or aluminum that has low acoustic impedance but has a low

20 resistivity is used as the electrodes. Thus, a duplexer having excellent characteristics can be produced.

[Fifth Embodiment]

An embodiment of the present invention will now be described with reference to Fig. 25.

25   For the convenience of description, components having

the same function as those of the components shown in the

first embodiment to the fourth embodiment have the same

reference numerals and the description is omitted.

In the present embodiment, as shown in Fig. 25,

5   resonators of a receiving filter 6 can use fundamental waves.

The resonators using fundamental waves can have an

electromechanical coupling coefficient k^2_{eff} larger than that

of the resonators using second harmonic waves, which are

shown in Figs. 2 to 4 and Fig. 9.

10   Consequently, a pass band required in the receiving

filter can be provided.

For example, a duplexer may include resonators of the

receiving filter 6 having a piezoelectric thin film composed

of AlN and using fundamental waves, and resonators of the

15   transmitting filter 5 having a piezoelectric thin film

composed of ZnO and using second harmonic waves. Thus, a

duplexer having excellent characteristics can be achieved.

A communication device using the duplexer described in

the above embodiment will now be described with reference to

20   Fig. 24.

At the receiving side (Rx side) wherein receiving is

performed, the communication device 600 includes an antenna

601, an antenna common / RF Top filter 602, an amplifier 603,

an Rx interstage filter 604, a mixer 605, a 1st IF filter

25   606, a mixer 607, a 2nd IF filter 608, a 1st+2nd local

synthesizer 611, a temperature compensated crystal
oscillator (TCXO) 612, a divider 613, and a local filter 614.

As shown by the double lines in Fig.12, the
transmitting from the Rx interstage filter 604 to the mixer
5   605 is preferably performed with balanced signals so as to
secure the balance.

At the transceiving side (Tx side) wherein transmitting
is performed, the communication device 600 shares the
antenna 601 and the antenna common / RF Top filter 602, and
10 includes a Tx IF filter 621, a mixer 622, a Tx interstage
filter 623, an amplifier 624, a coupler 625, an isolator 626,
and an automatic power control (APC) 627.

The duplexer described in the above embodiment can be
suitably used as the Rx interstage filter 604 and the RF Top
15 filter 602.

The present invention is not limited to the above
embodiments and various modifications are possible within
the scope shown in the claims. The technical field of the
present invention also includes embodiments obtained by
20 appropriately combining technical methods disclosed in the
different embodiments.

Industrial Applicability
The branching filter including filters having
25 piezoelectric thin film resonators of the present invention

can be applied to communication devices such as a cellular phone.